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ENERGY SAVINGS THROUGH EFFECTIVE LIGHTING CONTROL

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1. INTRODUCTION

Lighting is one of the largest energy loads in a large commercial building. Lighting typically accounts for 35-50% of the electrical consumption which, in turn, dominates the total energy costs in a building. Since Edison's day, there has been a 100-fold increase in the efficacy of lighting sources. Relatively little progress, however, has been made in reducing consumption through effective lighting management - using the optimal amount of light, where needed, and when needed.

Commercial lighting control is an area where the potential for major energy saving exists. A number of new products have begun to emerge which focus on lighting control. To identify promising technologies and to expedite their adoption by building owners, the Department of Energy funded a program by Lawrence Berkeley Laboratory to test new, commercially available lighting controls in an actual office environment. The tests were designed to demonstrate the following:

(1) which control strategies have the greatest impact and why

(2) economic trade-offs between control cost and savings potential

(3) acceptability of the controls to occupants

(4) control reliability.

Two test sites were chosen; one at the Pacific Gas & Electric Co. in San Francisco to test dimming-based control, the other at the World Trade Center in New York City to evaluate relay (on/off or stepped) controls. This paper discusses some of the preliminary results from the work at the World Trade Center, which was supervised by the Port Authority of New York. A complete analysis of the tests and results is presently under preparation by author F. Rubinstein.

2. TEST PLAN

To provide the degree of control necessary to evaluate a wide range of control strategies and techniques, every ballast on the 58th floor of the World Trade Center was retrofitted with a relay (Fig. 1). By selectively switching the relays, it was possible to make any of the 6-lamp, 3-ballast fixtures go to 1/3, 2/3, full on or off. (For even finer resolution, it was possible to turn on or off the two outside lamps on either end of the fixture.)

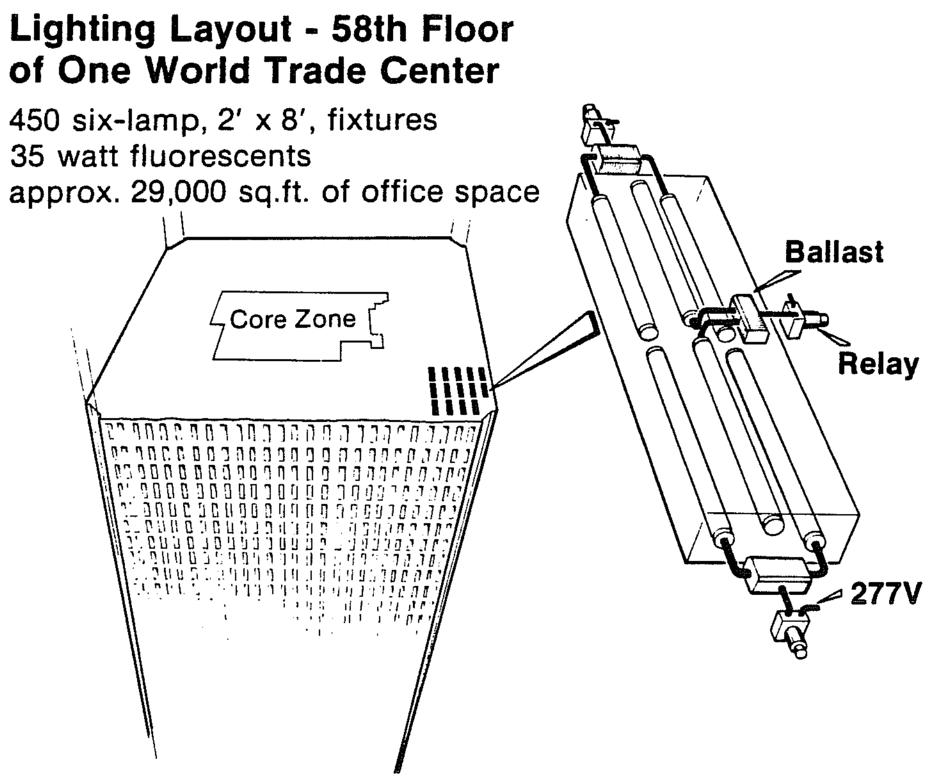


Figure 1.

The 1350 relays were controlled by a programmable lighting control system which allowed independent scheduling of each relay, monitoring of daylighting thresholds with appropriate relay shedding, and manual overrides of the lighting activated by the occupants' existing touchtone telephones (Fig.2). In addition, all relay activity was monitored and stored on tape to provide a record of consumption cross-referenced to particular events.

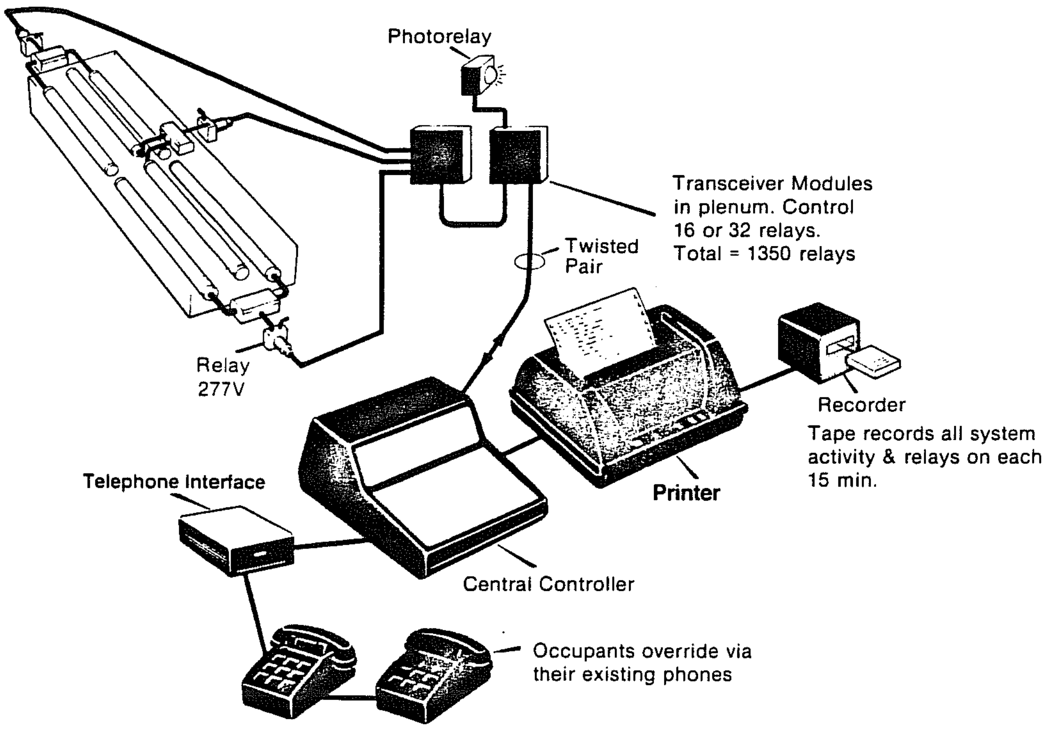


Figure 2.

A series of one-to-two week tests focused on finding the most effective ways to schedule lighting levels to match a task, allow for daylighting, and provide occupancy-based control. Variables affecting each of these general functions were manipulated to determine their impact or the degree to which the strategy could be pushed. (Fig. 3)

PRINCIPAL FUNCTION	VARIABLES TESTED
Schedule Lighting Level to Match Task	• Tightness of Schedule • Need for Occupant Overrides • Size of Switching Zone
Daylighting	• Simple Reduction vs. Compound • Interaction with Scheduling
Occupancy-Based Control	• Quadrant Control vs. Zone Switching

Figure 3.

The tape containing the activity record for each test was decoded by a computer program developed by the Lawrence Berkeley Laboratory, Windows and Daylighting Group. The program provided an event listing by time, daily energy consumption in "relay hours," and a plot of the relays on throughout the day. Figure 4 shows the plot for one of the initial tests and compares this to the normal operation of the floor which would have all 1350 relays on from 6:30 a.m. to 1:00 a.m. to provide for the earliest arrivers and possible late cleaning operation. This operating schedule at the World Trade Center was dictated by the fact that the lights are either on or off and local control by the cleaning crew is unacceptable; i.e., the cleaning crew requires some lights to be on whenever they might enter a floor.

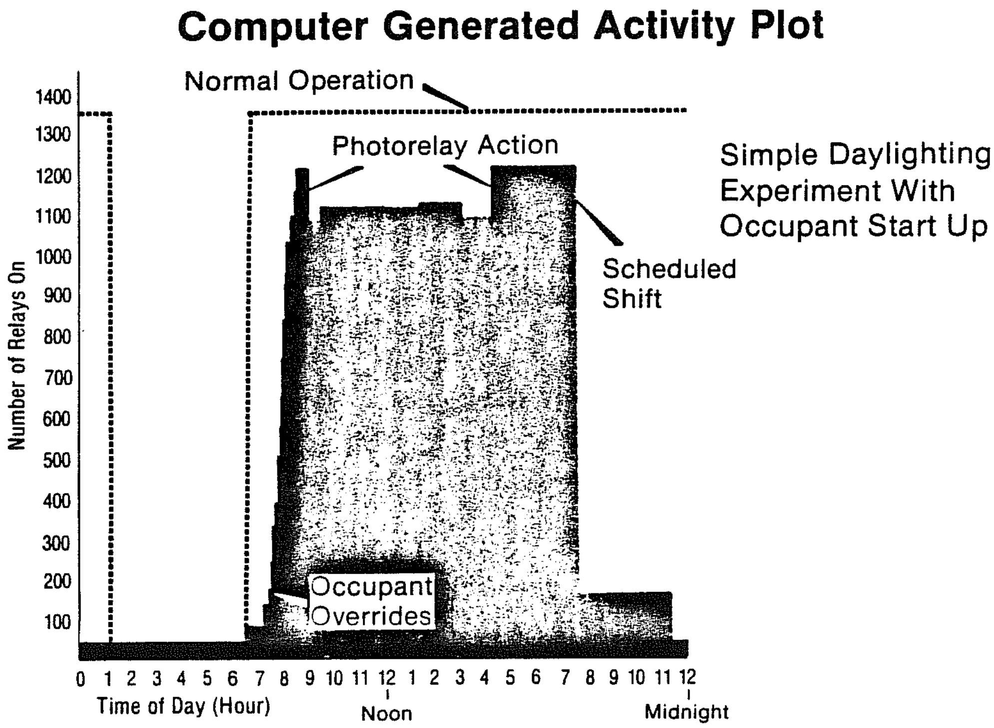


Figure 4.

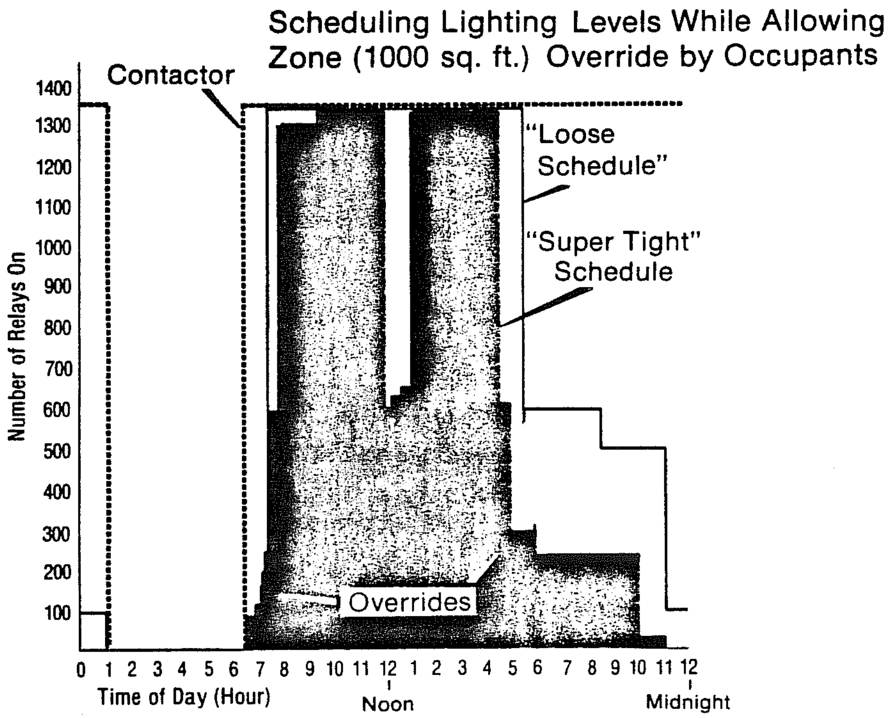
3.0 RESULTS

The results are best summarized by comparing the activity plots. These plots represent typical days within a test. Daily results from any test were normally very consistent. In some cases, the plots from two tests are combined to provide a clearer view of the impact of a key variable.

3.1 Scheduling Lighting Levels to Match Task

This series of tests focused on progressively tightening the lighting schedule. The floor was divided into zones of approximately 1000 ft^2 each. Anyone within a zone who came in early or stayed late could turn the lights in his zone back on by dialing the central computer and then dialing his special override code. This code number and the time of the override were recorded automatically.

The largest savings achieved by any one test (32%) was accomplished by reducing lighting levels after 5:30 p.m. to one-third of the full lighting level ("loose" schedule in Fig. 5). Progressive tightening of the schedule ("super tight" schedule) reduced energy consumption an additional 24% relative to the "loose" schedule operation. In other words, relative to contactor on/off control, the "super tight" schedule reduced daily consumption of energy for lighting by almost one-half. The presence of overrides on the activity plot underscore the need for this capability if tight automatic schedules are to succeed. If the override were not provided, it is logical to assume that occupants would complain to management.



SAVINGS

	Relay Hrs.	Reduction %	
Contactor on/off Control	25,000	Base	
"Loose" Multilevel Schedule with Zone Override	16,900	32%	24%
"Supertight" Multilevel Schedule with Zone Override	12,800	49%	

Figure 5.

3.2 Daylighting

In the daylighting experiments, lighting loads in perimeter areas of the floor were shed when sufficient daylight was available. In order to sense the amount of incoming daylight, two photo-relays (of different sensitivities) were installed on each building facade looking outwards. The first photo-relay tripped at approximately 300 footcandles - typical of an overcast day when viewed through the 30% transmittance glass. The second was set at 1000 footcandles and could only trip when exposed to direct sunlight. In the simple daylighting tests, only the fixtures in the perimeter zone were affected (Fig. 6). These were lowered from full lighting to 1/3 when the 300 fc photo-relay tripped. In the compound test, the fixtures in the "midzone" were also lowered from full lighting to 2/3 when the 1000 fc (direct sunlight) photo-relay tripped.

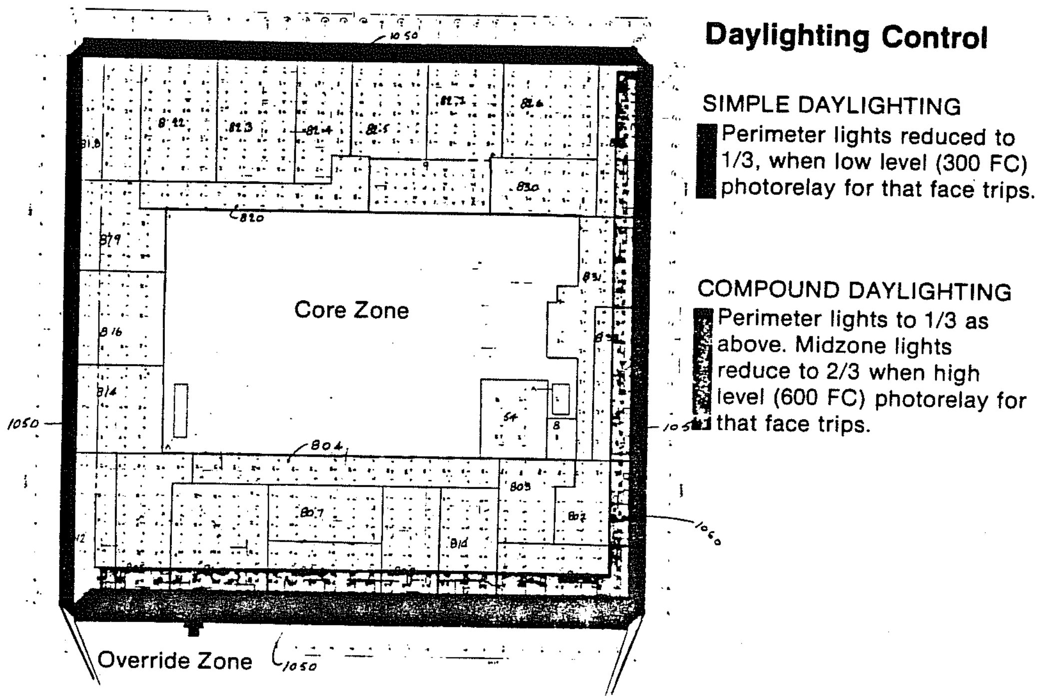
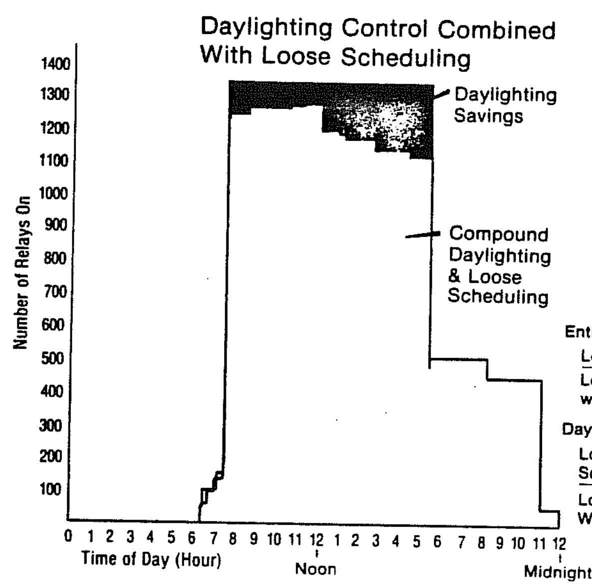


Figure 6.

Figure 7 shows the results of one of the tests in which compound daylighting was combined with the "loose" schedule operation. For all the lighting on the floor (daylit and non-daylit zones), daylighting reduced energy consumption by 12% relative to the loose schedule operation. If one considers the lighting load in the daylit areas only, then daylighting saved 29% relative to the loose schedule (see table accompanying Fig. 7). The difference in the energy savings is a consequence of the fact that daylighting impacts energy use only in a daylit portion of a building.

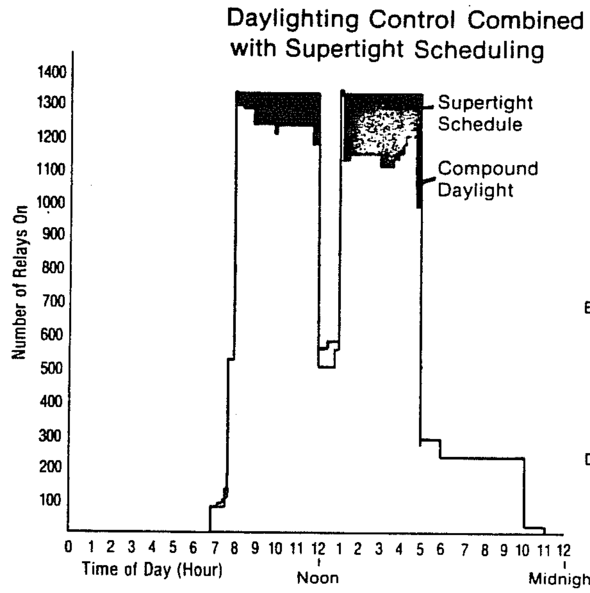


SAVINGS

	Relay Hrs.	% Reduction
Entire Floor		
Loose Schedule	14,900	Base
Loose Schedule with Daylight	13,100	12%
Daylight Zone Only		
Loose Schedule	6,800	Base
Loose Schedule With Daylight	4,800	29%

Figure 7.

Figure 8 shows the effect of compound daylighting used in conjunction with the "supertight" schedule operation. Notice that the energy savings attributable to daylighting is less than that shown in Fig. 7, since the very tight schedule reduced the hours during which daylighting had an impact.



SAVINGS	Relay Hrs.	% Reduction
Entire Floor		
Supertight Schedule	12,800	Base
Supertight Schedule with Daylight Control	11,900	7%
Daylight Zone Only		
Supertight Schedule	5,100	Base
Supertight Schedule with Daylight Control	4,200	18%

Figure 8.

3.3 Occupancy-Based Controls

The effect of zone size on the savings associated with occupancy control was remarkable. In this set of experiments, the lights were automatically scheduled down at lunch and at the end of the day - occupants turned them on manually with their phones. The first tests used large switching zones in which entire quadrants of the floor (about 7000 ft^2) could be set to one of four levels (off, 1/3, 2/3, or on). In other words, the first occupant to arrive in each quadrant would turn on all the lights in that quadrant. In the second set of tests, switching zones of about 1000 ft^2 were used. The functional dependence of energy savings on switching zone size is shown dramatically in Fig. 9. It was noted that while quadrant control reduced energy consumption by 29% relative to contactor on/off control, significantly greater energy savings resulted when 1000 ft^2 zones were used. The energy savings obtained with zone control (19% relative to quadrant control) is a result of the reduced impact of overrides on noon-hour and after-hours energy use when smaller switching zones were employed. Note also that with zone control, not all the zones were switched on during the afternoon. This is attributable to zone vacancies when occupants were out on site visits.

3.4 Additive Impacts

The full impact of the various tests taken separately and in combination is summarized in Fig. 10. Compared to the World Trade Center's normal operation, a total savings potential of 52% was measured when compound daylighting was used in conjunction with tight scheduling.

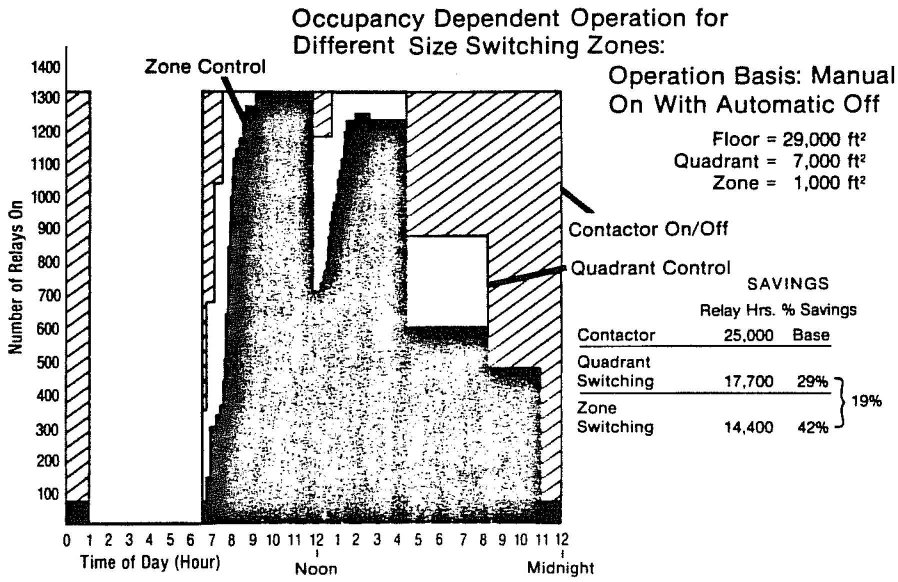


Figure 9.

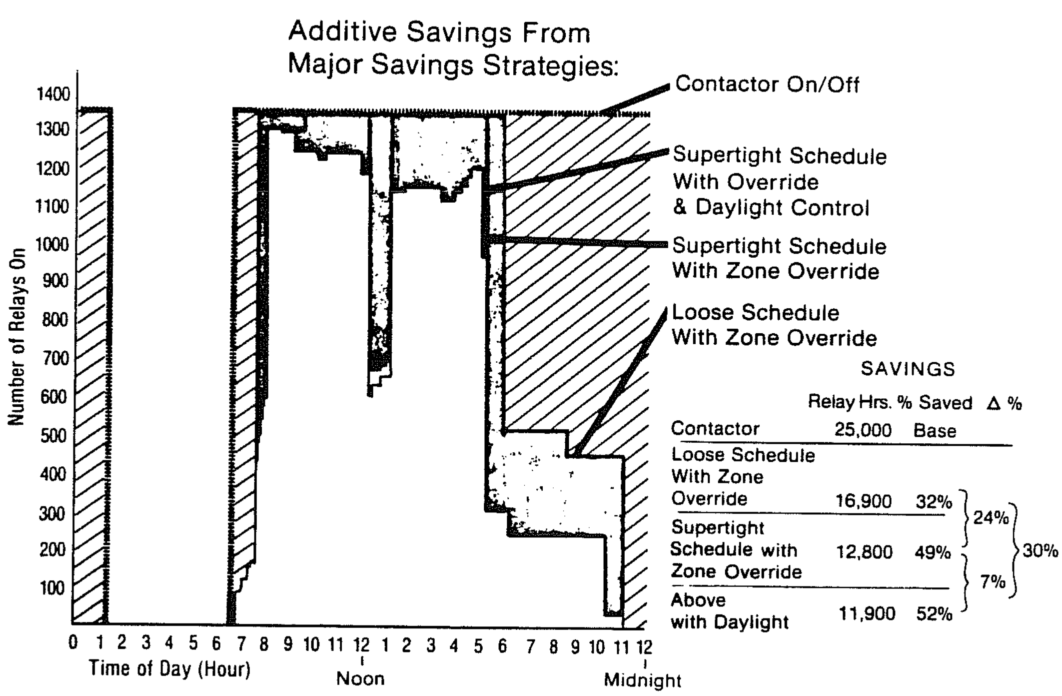


Figure 10.

4. ECONOMIC TRADE-OFFS

The major factor affecting control cost is the degree of control or resolution provided. The chart below (Fig. 11) shows estimates of the cost/ft^2 for different degrees of switching for a new construction project. Simple, contactor, multiple-level switching could save 18% compared to the on/off operation at the World Trade Center.* This would translate to a $0.13/ft^2 savings per year with an incremental cost of $0.06/ft^2 - a 6-month payback. Multi-level switching of 1000 ft^2 zones using the loose schedule with occupant overrides also shows a fast payback - 8 months - relative to on/off operation.

Economic Comparisons of Major Control Configurations

Incremental Savings ($/sq.ft./yr) & Payback at 5¢/KWH

Compare ▶ to ▼	Approximate cost/sq.ft.	Contactor on/off	Contactor* multilevel	1000 sq. ft. Zone, multilevel with loose schedule & overrides
Contactor on/off by floor	$0.07 **	same		
Contactor multi-level by floor	$0.13	$0.13 6 Mo.	same	
1,000 sq. ft. Zone Multi-level with loose schedule & overrides	$0.23	$0.23 8 Mo.	$0.10 12 Mo.	same
1,000 sq.ft. Zones Multi-level with tight schedule & Daylight Control	$0.30	$0.37 7 Mo.	$0.24 9 Mo.	$0.14 6 Mo.

* Multilevel contactor assumes full lighting from 6:30 AM to 8:00PM, 1/3 from 8:00 PM to 1:00 AM.

** Field hardware & installation cost only. Add $10-20 M for central intelligence.

Figure 11.

Figure 11 permits the reader not only to compare a particular energy-conserving strategy with simple on/off control, but also to compare alternative energy-conserving scenarios. For example, the cost of installing controls for multi-level zone control with tight scheduling and daylighting is only $0.07/ft^2 over the cost of multi-level zone control with loose scheduling. Since the incremental cost savings is $0.14/ft^2/yr ($0.37/ft^2/yr - $0.23/ft^2/yr), the payback is 6 months.

5. RELIABILITY AND WORKER ACCEPTANCE

Hardware failures were minimal. During the one year of operation less than 1/2% of the relays failed and approximately 2% of the transceivers failed. Reaction to the system was positive, and today the system is being retrofitted to control all of the lighting in the World Trade Center.

6. CONCLUSIONS

- Lighting control can affect consumption positively and significantly - a maximum of 52% in this test.
- Relay-based (stepped level) daylighting control is acceptable to occupants and significant.

* assuming $.05 per KWH and 3 Watts/ft^2

- The payback on relay-based lighting control for new construction is extremely attractive.

- Relay-based automatic lighting controls are acceptable to the occupant and show high reliability.

The major value of the tests was not in the 52% savings achieved on the positive economics, but in the insight gained into why certain strategies were successful, how strategies interact, the relationship of control savings to the use of space, and the importance of occupant-based overrides to insure positive reactions to the system.

7. ACKNOWLEDGEMENTS

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The authors acknowledge the contribution of the Port Authority of New York's Energy Conservation Group. The valuable assistance of Mahmut Karayel (LBL Windows and Daylighting Group), who developed the computer program used to decode and reduce the experimental data, is also noted.